SURVIVAL AND GROWTH OF NATIVE HARDWOODS ON A RECLAIMED SURFACE MINE[1]

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Abstract: Current regulations for commercial forestry post-mining land use require the placement of more than 1.5 m of weathered brown sandstone and topsoil on the spoil surface after regrading to the final land topography. Commercially valuable hardwood trees are to be planted in this substrate, and survival and growth of these trees must be monitored over a 12-year bonding period. Success of the commercial hardwood planting is based on the growth of white pine (*Pinus strobus*), which must achieve greater than 0.5 m of average growth per year for four or more consecutive years. The objective of this research is to evaluate whether tree survival and growth in weathered brown sandstone is superior, equal, or inferior to tree survival and growth in unweathered gray sandstone. Three, 2.8-ha plots were constructed with varying substrates at the surface: 1) 1.5 m of weathered brown sandstone, 2) 1.2 m of weathered brown sandstone, and 3) 1.5 m of unweathered gray sandstone. Half of each 2.8-ha plot was compacted, where dozer tracks completely covered the surface, while the other half had only one pass of a dozer. Percent fines on brown sandstone decreased from 52% the first year to 39% the second year, while on the gray sandstone it decreased from 38% to 30%. Percent sandstone on the brown sandstone treatment increased from 45% to 57%, while on gray sandstone it increased from 59% to 66%. Brown sandstone had a pH of 5.3 and an EC of 416, while gray sandstone's pH was 7.9 and EC was 205 in 2005. In March 2005, 11 hardwood species were planted in each plot. After one growing season, tree survival on the non-compacted areas of each treatment was >99% across all species, whereas the compacted areas showed 88% tree survival. Average height and diameter for each species was also obtained after one growing season and showed little difference between treatments across all species (average height 38.6 cm for 1.5 m brown sandstone vs. 38.9 cm for 1.5 m gray sandstone and 39.6 cm for all compacted vs. 41.4 cm for all uncompacted treatments).

Additional Key words: substrate composition, substrate depth, compaction, tree survival

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Introduction

When large scale surface mining started in West Virginia in the early 1900's, reclamation was unregulated and seldom occurred. These early mining techniques, such as the shoot and shove method, simply blasted the overburden material and shoved it down slope which left the land in a condition suitable for tree growth because the areas had largely weathered uncompacted materials on the surface. Starting in the 1930's and 40's coal operators were required to reclaim the land back to a suitable form. At first, some experiments were done to reclaim land back to forest by planting early successional trees such as black locust and autumn olive (Skousen et al. 2006). A few hardwood species like black cherry and oak were planted and some survived and grew (Skousen et al. 1994). A few decades after this, laws and regulations were passed in the eastern United States that promoted seeding reclaimed areas with grasses and legumes, which produced a quick economic return to the land owner through livestock grazing or sale of hay. However, good maintenance practices are required to keep these areas productive. When these areas go unmanaged, trees invade and gradually move through many stages of plant succession that can take many decades before a forest of commercially valuable timber will dominate.

As the acreage of disturbed land continues to increase, people have become interested in reclaiming disturbed areas into productive forests. Doing so requires the consideration of many factors during initial reclamation including substrate type and depth, compaction of soil medium, ground cover type and density, and tree species selection (Torbert, 1995; Torbert and Burger, 1990; Torbert et al., 1988, 1990; Vogel, 1981). Consideration of these factors while reclaiming and planting could lead to a quicker economic return from tree harvesting.

More recent developments in reclamation include the return of land to approximate original contour (AOC). As a general rule, the post mining contours must be within 20 to 30 % of the original contours. Returning land to AOC can be a costly procedure for coal companies and some surface mining operations can seek variances from AOC to create a more gently sloping condition for other post-mining land uses. Currently companies with AOC variances are limited to either an industrial use or commercial forestry as post mining land use.

Industrial post mining land uses include airports, high schools, prisons, golf courses, and other businesses that need flat land or rolling landscapes on which to build. Commercial forestry requires the planting and establishment of commercially valuable tree species and includes a 12-year bonding period where trees must achieve growth standards. White pine was chosen as an indicator species for growth success of all trees and this species must achieve 4 or more years of at least 0.5 m of growth per year. Failure to meet such standards may require companies to pay up to twice the money as in the reclamation bond. When reclaiming mountaintop mining sites, revegetation is done soon after grading to control erosion. To achieve bond release within 12 years, it is important to plant trees early and to monitor their progress.

The objective of this study is to determine the effects of substrate type and depth, as well as compaction on the survival and growth of 11 tree species on a mountaintop mine in West Virginia.

Site Description

Catenary Coal Company at the Samples Mine in Kanawha County, West Virginia established three demonstration plots composed of two soil mediums. In January of 2005, three, 2.8-ha

(7-ac) plots were established: the first had 1.5 m (5 ft) of weathered brown sandstone (5B) placed on the surface, the second had 1.2 m (4 ft) of weathered brown sandstone (4B) placed on the surface, and the third had 1.5 m (5 ft) of unweathered gray sandstone (5G) placed at the surface. These plots were constructed on a nearly level slope adjacent to one another with a 6-m (20-ft) buffer region separating them. After placement, one-half of each plot was compacted (D-10 Caterpillar dozer tracks completely covering the surface, approximately 4 passes), while the other half was uncompacted with only one or two passes with the same dozer.

In March 2005, 11 species of 2-0 stock trees were planted on these areas and some species were planted in greater numbers than others (Table 1). Trees were planted by a commercial tree planting company on a 2.4-m by 2.4-m (8 by 8 ft) spacing, which gives a planting density of 1680 stems per ha (680 stems per ac). Using 15-25 people, planters walked across a plot in a line and planted trees every 3 to 4 steps. Each planter had only two or three tree species in his planting bag, so the trees were not evenly planted across the site. Dibble bars were used to open a hole in the substrate, the tree roots were thrust into the hole, and the tree planter then closed the hole by pushing the soil together with his shoe; he then took a few steps and opened another hole. White pine (*Pinus strobus*), which is being used as the indicator species, was planted at a rate of approximately 49 stems per ha, or 140 stems for each demonstration plot. The number of white pine is higher than the requirements in the regulations because an adequate number of trees must be available for growth increment verification and limited destructive sampling. One year after completion of tree planting, the area was hydroseeded at a reduced seeding rate than that normally used in this area (Table 2). The planting of these 150,000 trees on 303 ha (750 ac) (both demonstration plots and Experimental Practice areas) was done March 17-21, 2005.

Table 1. Rates and species of trees planted in 2005 at Catenary's Samples Mine in Kanawha County, West Virginia.

Species	Total Number Planted	% of trees planted
Red Oak (*Quercus rubra*)	33,000	22%
White Oak (*Quercus alba*)	26,250	17.5%
Chestnut Oak (*Quercus prinus*)	11,500	7.7%
White Ash (*Fraxinus americana*)	24,750	16.5%
Yellow Poplar (*Liriodendron tulipifera*)	15,000	10%
Sugar Maple (*Acer saccharum*)	15,000	10%
Black Cherry (*Prunus serotina*)	4,500	3%
Black Locust (*Robinia pseudoacacia*)	5,500	3.7%
Dogwood (*Cornus alternifolia*)	5,500	3.7%
Red Bud (*Cercis canadensis*)	4,500	3%
White Pine (*Pinus strobus*)	4,500	3%
Total	150,000	100%

Table 2. Species and rates of ground cover hydroseeded at Catenary's Samples Mine in Kanawha County, West Virginia.

Reduced Rate of Application Species	Rate	Heavy Rate of Application Species	Rate
Red Top (*Agrostis gigantea*)	2.2 kg/ha	Perennial ryegrass (*Lolium perenne*)	2.2 kg/ha
Perennial ryegrass (*Lolium perenne*)	2.2 kg/ha	Red top (*Agrostis gigantea*)	2.2 kg/ha
Birdsfoot trefoil (*Lotus corniculatus*)	11 kg/ha	Orchard grass (*Dactylis glomerata*)	5.5 kg/ha
		Kobe lespedeza (*Lespedeza cuneata*)	5.5 kg/ha
		Weeping lovegrass (*Eragrostis curvula*)	2.2 kg/ha
		Birdsfoot trefoil (*Lotus corniculatus*)	11 kg/ha
		Ladino clover (*Trifulium repens*)	3.3 kg/ha
Total	15.5 kg/ha		32 kg/ha

Methods

Tree survival and growth were determined by establishing two transects across each plot in an "X" pattern. Each transect was 196 m (643 ft) long and 3 m (10 ft) wide, which allowed for a sufficient number of trees of all species to be sampled. To our surprise, initial observations revealed that very few of the white pine survived. Therefore, for first year measurements (2005 growing season), the 3-m-wide transects were increased to 8.5 m (28 ft) wide in order to sample enough live white pines, while the other tree species were evaluated by using the 3-m-wide transects. Measurements for the 2006 growing season were done using the 3-m-wide transects because more white pine had been planted in each demonstration plot and in the experimental practice area. The white pines that were measured with the 8.5-m transect were still measured in 2006 if still alive. Every tree within the transects were identified and measured for height and diameter at approximately 3 cm (1.2 in) above the soil surface.

Soil samples were collected from the upper 20 cm (8 in) at five randomly selected points along each transect. This equates to five soil samples being removed for each treatment (i.e., compacted gray sandstone being one treatment). These samples were individually weighed, then sieved to separate the soil samples into the coarse fraction (>2mm) and the fine fraction (<2mm). The fine fraction was weighed to determine percent fines. Percent sandstone was determined by using the coarse fraction and removing all the rocks and particles that were not sandstone, then weighing the sandstone fragments. Soil chemical properties were determined on the fine fraction of soil.

Soil pH and soluble salts were determined on a 1:1 mixture with deionized distilled water and shaken. A Beckman 43 pH meter was used to determine the pH of the mixture and a Microprocessor Conductivity Meter LF 3000 was used to determine electrical conductivity. Soil samples were extracted with Mehlich 1 extract solution, which is composed of approximately 0.05N HCl and 0.025N H_2SO_4. After the extract is passed through the soil sample it was analyzed with a Perkin Elmer Plasma 400 emission spectrometer for Zn, Al, Fe, Mn, Mg, P, K, Ca, and Ba. Nitrogen, C, and S were determined by putting dried and sieved samples into a Leco TruSpec CHN analyzer.

Results

Soils

Average pH was higher on the gray sandstone as compared to the brown sandstone (Table 3). The high pH of unweathered gray sandstones is expected to be in the 7-8 pH range (Thomas et al., 2001). However, experience and research shows that within several years, the pH of these mine soil materials decreases to lower levels upon weathering, often attaining a pH as low as 5.0. This is anticipated to happen over time on the gray sandstone plots. The pH of the brown sandstone plots was approximately 5.0. Native forest soils and weathered soil materials in this region commonly vary from 4.5 to 5.5.

Table 3. 2005 and 2006 soil properties on three soil medium types under two compaction treatments (4B-C = 4-ft Brown Sandstone-Compact, 5G-NC = 5-ft Gray Sandstone-Not Compact) at Catenary's Samples Mine in Kanawha County, West Virginia.

	Treatments					
Properties	5B-C	5B-NC	4B-C	4B-NC	5G-C	5G-NC
pH 2005	6.0	4.7	4.7	5.2	7.6	8.3
pH 2006	5.8	5.7	4.5	4.6	8.2	8.2
EC (µs/cm)	399	433	525	281	212	200
% fines 2005	50	53	49	48	40	36
% fines 2006	43	36	41	37	29	31
% Sandstone 2005	47	44	48	50	57	61
% Sandstone 2006	55	61	58	61	67	65
% Carbon 2006	2.3	1.2	2.0	1.7	2.4	2.7
% Nitrogen 2006	.06	.01	.05	.06	.08	.07
% Sulfur 2006	.32	.26	.29	.27	.24	.25

Conductivity was about twice as high on the brown sandstone compared to the gray sandstone. It was expected that the fresh materials (unweathered gray sandstone) would have higher levels of soluble salts due to the release of these materials upon exposure to rain and air. However, perhaps not enough time has elapsed for these salts to be seen from these unweathered materials.

The percent sandstone was greater on the gray sandstone plot compared to the brown sandstone plots (Table 3). This may be due to the fact that the brown sandstone was already weathered to some degree, which allowed faster degradation of sandstone rocks into smaller particles.

Concentrations of several elements showed wide variation across treatments (Table 4). One would expect the lower pH brown sandstone materials to have greater extractable amounts of elements, but this expected result was not consistent. There does, however, seem to be greater amounts of phosphorus and calcium in the gray sandstone compared to the brown sandstone (Table 4). Carbon, nitrogen, and sulfur concentrations were variable among the brown sandstone plots (Table 5.)

Table 4. 2005 Average elemental concentrations on three soil medium types under two compaction treatments (4B-C = 4-ft Brown Sandstone-Compact, 5G-NC = 5-ft Gray Sandstone-Not Compact) at Catenary's Samples Mine in Kanawha County, WV.

	Treatments					
Element	5 B-C	5 B-NC	4 B-C	4 B-NC	5 G-C	5 G-NC
	------- mg/kg -------					
Al	90 b*	119 ab	141 a	125 a	61 c	40 c
Ba	1.2**	.74	.65	.99	1.3	1.1
Fe	64 b	71 b	86 b	175 ab	123 ab	211 a
Mn	75 ab	82 ab	123 a	71 ab	51 bc	231 c
Mg	249	165	234	188	190	184
P	36 b	20 b	22 b	23 b	59 a	63 a
K	66 b	71 ab	78 a	74 ab	68 b	65 b
Ca	569	364	461	464	637	568
Zn	2.5	2.5	2.6	3.7	4.4	5.7

*Means for each element with the same letter are not significantly different at Alpha = 0.05 level
**Means with no letters are not significantly different at Alpha =0.05 level

Tree Survival and Growth

Overall tree survival was good for all species except white pine (Table 6). Almost 40% of the white pine did not survive from the time they were planted in the spring until the end of that summer. This was most likely due to poor quality of seedlings from the supplier, and it is felt that many of these trees were dead even as they were being planted. In the spring of 2006 more white pines were planted in the demonstration plots. Survival of other species varied from 98% for chestnut oak (*Quercus prinus*) across all plots to 75% for black cherry (*Prunus serotina*). It is also interesting to note that total tree survival was almost the same for the 5 ft brown (5B) sandstone plot (98%) and the 5 ft gray (5G) sandstone plot (100%).

Table 6. 2006 Percent survival of 11 planted species on three soil medium types under two compaction treatments (4B-C = 4-ft Brown Sandstone-Compact, 5G-NC = 5-ft Gray Sandstone-Not Compact) at Catenary's Samples Mine in Kanawha County, WV.

	Treatments						
Species	5B-C	5B-NC	4B-C	4B-NC	5G-C	5G-NC	Average
	%						
Black Cherry	66	100	50	33	100	100	75
Black Locust	100	100	100	100	100	100	100
Chestnut Oak	100	100	100	88	100	100	98
Dogwood	100	100	67	83	100	100	92
Red Bud	66	100	100	100	100	100	94
Red Oak	85	85	96	83	84	100	89
Sugar Maple	92	100	100	90	100	100	97
Tulip Poplar	60	100	82	90	91	100	87
White Ash	88	100	93	100	100	100	97
White Oak	75	100	87	92	91	100	91
White Pine	50	50	77	62	66	75	63
Average	94	80	83	87	98	94	

The average tree height and diameter is variable throughout the study, and at this point in the experiment may still be closely tied to the size and quality of individual trees when planted. Percent growth increase of each species over the course of the first growing season can be seen in Tables 6 and 7. Black locust, white ash, and white oak showed the highest height increases while redbud and tulip poplar had negative growth because one or more of the trees sampled had the main stem die and resprout from the base of the stem. The effects of mine soil type and degree of compaction are not showing clear trends at this early stage of the study. We expect the next few years of growth to be relatively free of the effects of transplanting shock. Treatment effect on growth will be reported at that time.

Table 7. Percent average height increase over first growing season (2005-2006) on three soil medium types under two compaction treatments (4B-C = 4-ft Brown Sandstone-Compact, 5G-NC = 5-ft Gray Sandstone-Not Compact) at Catenary's Samples Mine in Kanawha County, West Virginia.

	Treatment						
Species	5B-C	5B-NC	4B-C	4B-NC	5G-C	5G-NC	Average
	------------------------------------%--						
Black Cherry	1	27	7	15	26	17	16
Black Locust	46	46	46	80	22	43	47
Chestnut Oak	10	13	9	10	10	19	12
Dogwood	4	-2	18	16	-10	2	5
Redbud	8	6	-20	-14	4	2	-2
Red Oak	14	17	10	4	6	6	10
Sugar Maple	6	1	3	2	4	9	4
Tulip Poplar	0	20	-34	-8	-2	12	-2
White Ash	26	38	11	19	23	13	22
White Oak	14	14	2	12	10	9	10
White Pine	193	57	28	8	34	15	56
Average	29	23	7	13	11	13	

Table 8. Percent average diameter increase over the first growing season (2005-2006) on three soil medium types under two compaction treatments (4B-C = 4-ft Brown Sandstone-Compact, 5G-NC = 5-ft Gray Sandstone-Not Compact) at Catenary's Samples Mine in Kanawha County, West Virginia.

	Treatment						
Species	5B-C	5B-NC	4B-C	4B-NC	5G-C	5G-NC	Average
	------------------------------------%---						
Black Cherry	12	20	24	136	13	24	38
Black Locust	56	40	52	66	47	18	47
Chestnut Oak	1	27	27	37	24	24	23
Dogwood	48	28	23	72	47	24	40
Redbud	15	16	17	37	26	20	22
Red Oak	23	22	17	31	29	26	25
Sugar Maple	12	26	15	20	31	24	21
Tulip Poplar	11	0	29	30	47	19	23
White Ash	33	19	34	31	37	23	30
White Oak	20	16	24	24	34	30	25
White Pine	30	221	58	34	49	36	71
Average	24	40	29	47	35	24	

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